

# Fabrication of Polymeric Micro-Optical Device

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## 1. Introduction

Development of information technologies enhances interest in mass optical memory systems and high-speed optical communication systems. In order to expand the applicable field of these systems, miniaturization and easy fabrication are important for optical devices.

Conventional technologies for miniaturization of the optical devices include optical waveguide devices<sup>1)</sup> and holographic optical elements<sup>2)</sup>, however, because of its severe coupling condition, an optical waveguide device must be aligned within an accuracy of a few microns. On the other hand, holographic optical elements have the disadvantages of low coupling efficiency and of strong wavelength dependence.

In order to solve these difficulties, we have developed a laser ablation (LAB) process to fabricate micro optical components. The components are formed on a semiconductor substrate and their sizes are of the order of sub millimeters. The LAB process can etch the polymer film at a high rate of 50 $\mu$ m/s without temperature rise and can form smooth surfaces. In this paper, we describe the fabrication techniques for optical planes using the LAB process.

## 2. Laser ablation system

In the LAB process using high-energy ultraviolet laser beams polymers are chemically decomposed and removed without heating, therefore, smooth bottoms and sidewalls of the etched holes can be obtained. Using these smooth surfaces as optical planes we have made out optical components by a fabrication process shown in Fig.1. A polymer film is glued on a Si substrate and is etched by the LAB process. Slant planes can be easily formed by the relative movement of the laser beam to workpieces<sup>3)</sup>.

Figure 2 shows the configuration of the LAB system. The light source is a KrF excimer laser operating at a wavelength of 248nm with a repetition rate of 200Hz and the peak power is 80W. The laser beam radiated from the source goes through a mask and a pattern on the mask is imaged on a workpiece put on a X-Y stage by an imaging lens with magnification of 1/4. The workpiece is etched vertically in the irradiated area and the depth of the etched hole is proportional to the number of laser pulses.

## 3. Fabrication

We have used a polycarbonate(PC) film as a starting material. The PC film shows good etching

characteristics for the LAB process and because of its amorphous property the etched surface is very smooth. The PC film, 200 $\mu\text{m}$  in thickness, has high transparency of more than 93% at a wavelength of 400nm. Moreover, it has the high glass transition temperature of 149 and good durability against UV irradiation.

The fabrication process of the device is as follows. First, a PC film (300 $\mu\text{m}$ -thick) was bonded on a Si substrate using a thermosetting adhesive sheet (50 $\mu\text{m}$ -thick). They were cured at 120 for 2 hours on a hot plate. Then the PC film was etched by the LAB process with a mask and outlines of components are formed. After that, vertical surfaces and slant surfaces are fabricated by the relative movement of the workpiece to the laser beam.

In order to stop the etching process at the surface of the Si substrate, the laser fluence on the workpiece surface was set at 750mJ/cm<sup>2</sup>. At this laser fluence, the etching rate of the PC was 50 $\mu\text{m/s}$  with the repetition rate of 200Hz. In the LAB process, carbon particles come from the decomposition of polymers and pollute the etched surfaces. To suppress the pollution, we ablated the workpiece in ambient gas including O<sub>2</sub> and cleaned it in ethyl alcohol with an ultrasonic bath.

Vertical or slant planes made by the LAB process are used as optical planes in this device, so that surface roughness of each plane must be less than  $\lambda/10$ . Since the planes were formed using edges of the mask pattern, we used a quartz mask with a chromium film patterned by electron beams.

As shown in Fig.3(a), a laser beam is usually irradiated over a mask aperture. When the aperture truncates the laser beam, the beam intensity profile on the workpiece shows wavy profile because of the diffraction effect of the beam. Moreover, the beam intensity profile radiated from the laser is not perfectly uniform. As the results, striation appears on sidewalls of the etched holes as shown in Fig.4(a).

As shown in Fig.3(b) we used a mask with a rectangular aperture whose width  $W_A$  was wider than a width of the laser beam  $W_L$ . (The size of the beam was 25mm $\times$ 8mm and the size of the aperture was 30mm $\times$ 2mm.) The beam intensity profile in the lateral direction on the workpiece became smooth because the beam was not diffracted in this direction. Moreover, to homogenize the accumulated total laser energy per unit of the irradiated surface, the workpiece was moved in the lateral direction at a constant speed. Consequently, striation on planes parallel to the lateral direction was eliminated as shown in Fig.4(b) and the RMS surface roughness measured by an interferometer was 18nm.

We fabricated slant planes moving workpieces during laser irradiation as shown in Fig.5. Since the accumulated total irradiated laser energy gradually varied along the moving direction, a slant plane with a slope along the direction could be obtained. The slant angle  $\theta$  is expressed with the moving velocity of the workpiece  $V$  and the etching rate  $D$ .

$$\theta = \tan^{-1}(D/V)$$

In the slant plane fabrication, the wider aperture shown in Fig.3(b) was used, however, striation also appeared on the slant plane as shown in Fig.5(a) with single-axis scanning because the beam intensity profile was not so uniform. To improve the uniformity of the accumulated total irradiated laser energy, we moved the workpiece in the X direction in a range of 120 $\mu\text{m}$  at a repetition rate of 40Hz with moving velocity  $V$  of 10 $\mu\text{m/s}$  as shown in Fig.5(b). Figure 6 shows a microscope

photograph of the slant plane. Using double-axis scanning method the striation was reduced as well as the vertical plane and the RMS surface roughness within a circle 150 $\mu$ m diameter was 28nm. Both vertical planes and slant planes formed by the LAB process are smooth enough to be used as optical planes.

## 5. Conclusion

We have fabricated polymeric micro-optical components having the advantages of small size, easy fabrication, and easy alignment. They are fabricated from a PC film on a semiconductor substrate by the laser ablation process and their heights are 300 $\mu$ m. The RMS surface roughness of the components was less than 28nm. The laser ablation technique is useful for micro-optics fabrication and has the potential to expand the applicable field of optical systems, such as optical memory systems and optical communication systems.

## References

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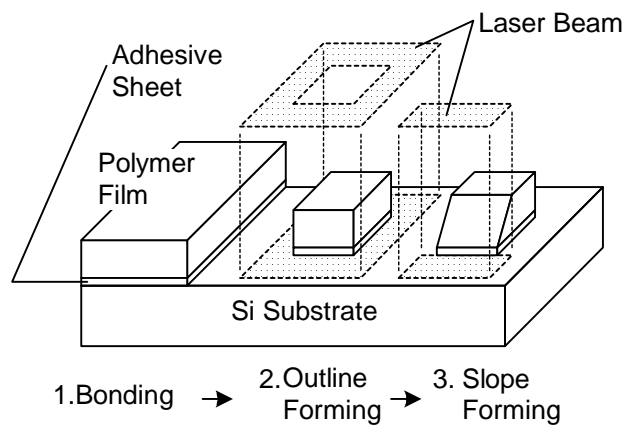


Fig.1. Schematic illustration of the micro optics fabrication by the laser ablation technique

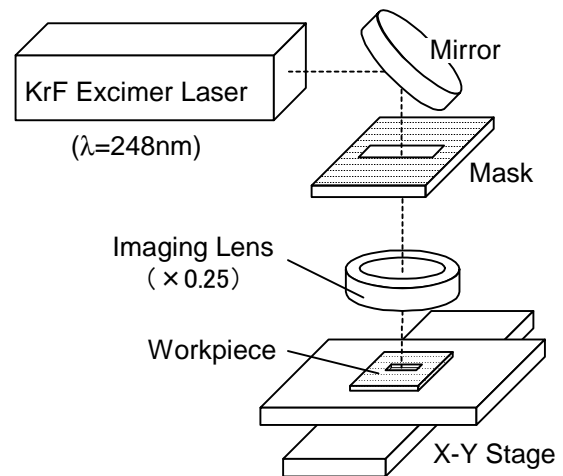


Fig.2. Configuration of the laser ablation system.

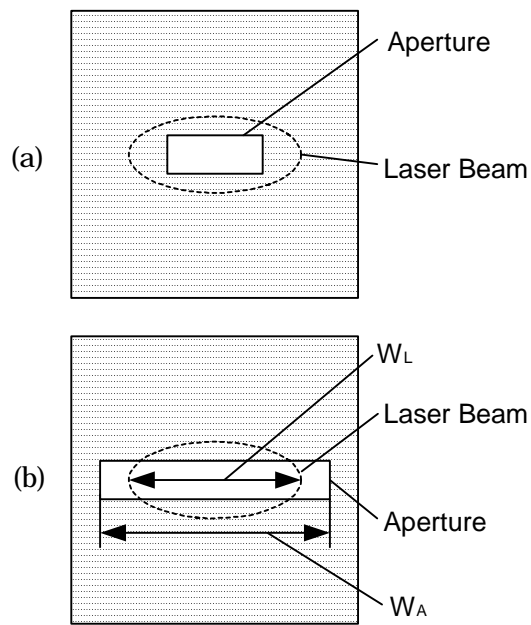


Fig.3. Mask patterns (a) Conventional mask (b) Mask with a wide aperture

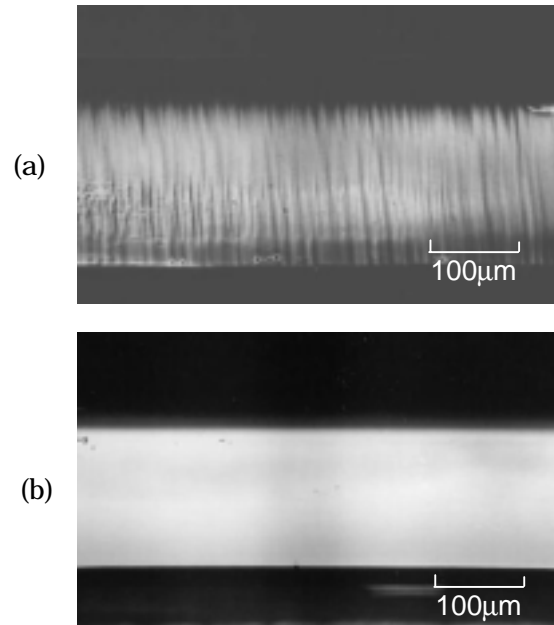


Fig.4. Microscope photographs of the vertical planes (a) Using a conventional mask (b) Using the mask with a wide aperture

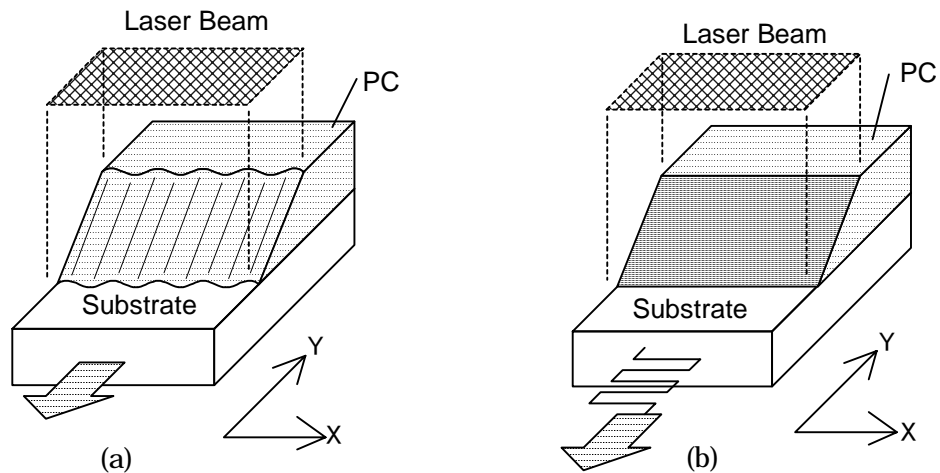


Fig.5. Schematic illustrations for the slope forming (a) single-axis scanning (b) double-axis scanning

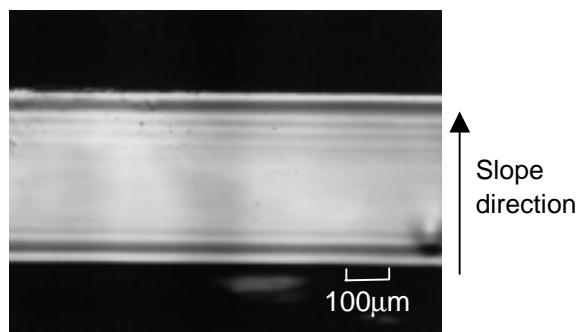


Fig.6. Microscope photograph of the slant plane